Attachment D

Economic Analysis of California Climate Policy Initiatives using the Berkeley Energy and Resources (BEAR) Model

Public Review Draft

Prepared for
California Cimate Action Team

By
David Roland-Holst, UC Berkeley

1 INTRODUCTION

For the last two years, economists at UC Berkeley have conducted independent research to inform public and private dialogue surrounding California climate policy. Among these efforts has been the development and implementation of a statewide economic model, the Berkeley Energy and Resources (BEAR) model, the most detailed and comprehensive forecasting tool of its kind. The BEAR model has been used in numerous instances to promote public awareness and improve visibility for policy makers and private stakeholders.[1] In the legislative process leading to the California Global Warming Solutions Act (SB32), BEAR results figured prominently in public discussion and were quoted in the Governor's Executive Order to carry out the act.

While researchers who developed and implement the BEAR model do not advocate particular climate policies, their primary objective is to promote evidenced-based dialogue that can make public policies more effective and transparent. California's bold initiative in this area makes it an essential testing ground and precedent for climate policy in other states, nationally, and internationally. Because of its leadership, the state faces a significantly degree of uncertainty about direct and indirect effects of the many possible approaches to its stated goals for emissions reduction. High standards for economic analysis are needed to anticipate the opportunities and adjustment challenges that lie ahead and to design the right policies to meet them.

2 THE BEAR MODEL

The Berkeley Energy and Resources (BEAR) model is a constellation of research tools designed to elucidate economy-environment linkages in California. The schematics in Figures 2.1 and 2.2 (below) describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the BEAR

[1] See e.g. Roland-Holst (2006ab, 2007a).

model.[2] For the purposes of this report, the 2003 California Social Accounting Matrix (SAM), was aggregated along certain dimensions. The current version of the model includes 50 activity sectors and ten households aggregated from the original California SAM. The equations of the model are completely documented elsewhere (Roland-Holst: 2005), and for the present we only discuss its salient structural components.

Structure of the CGE Model

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

[2] See Roland-Holst (2005) for a complete model description.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new California SAM estimated for the year 2003.[3] The result is a single economy model calibrated over the fifteen-year time path from 2005 to 2020.[4] Using the very detailed accounts of the California SAM, we include the following in the present model:

Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) functions.

In each period, the supply of primary factors — capital, land, and labor — is usually predetermined.[5] The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[6]

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply conditions in all markets.

Consumption and Closure Rule

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

[3] See e.g. Meeraus et al (1992) for GAMS. Berck et al (2004) for discussion of the California SAM.

[4] The present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries or combinations thereof.

[5] Capital supply is to some extent influenced by the current period's level of investment.

[6] For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes that the government deficit/saving is exogenously specified.[7] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the *Armington* assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a *Constant-Elasticity-of-Transformation* (CET) function.

Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

[7] In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

Figure 2.1: Component Structure of the Modeling Facility

BEAR is being developed in four areas and implemented over two time horizons.

Components:

1. Core GE model
2. Technology module
3. Emissions Policy Analysis
4. Transportation services/demand

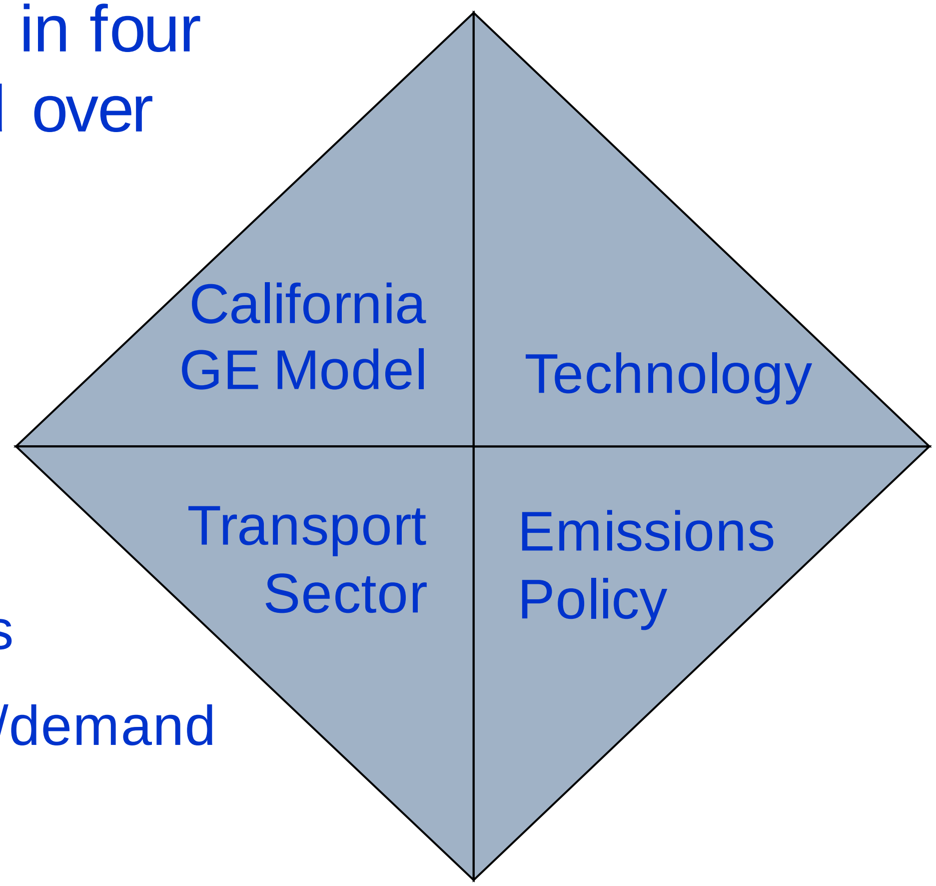
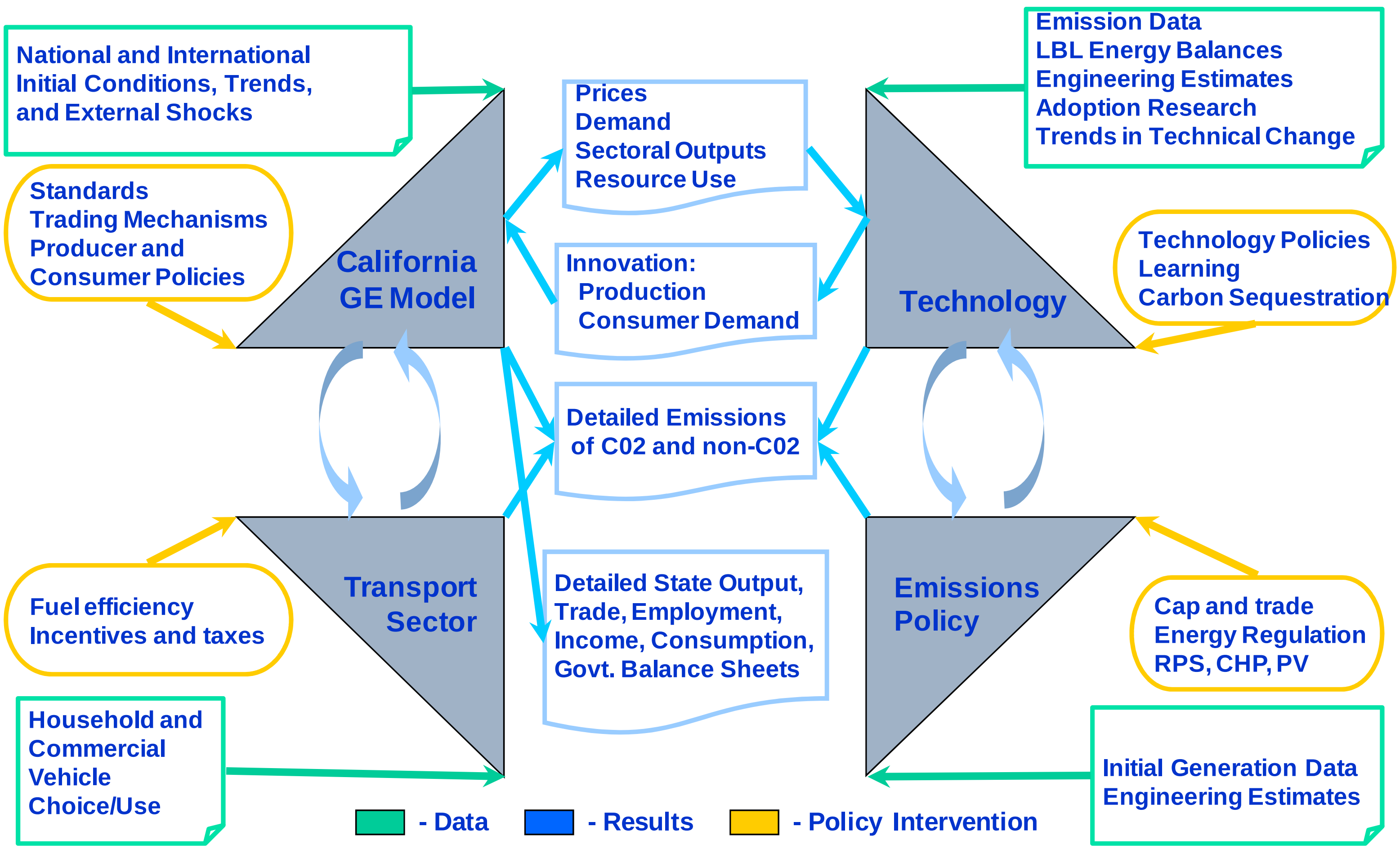


Figure 2.2: Schematic Linkage between Model Components



Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

The putty/semi-putty specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time.[8] When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

Modeling Emissions

The BEAR model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO2 and the other primary greenhouse gases, which are converted to CO2 equivalent. Following

[8]This involves computing in each period a measure of Harrod-neutral technical progress in the capital-labor bundle as a residual. This is a standard calibration procedure in dynamic CGE modeling.

standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential.[9] In this framework, emission levels have an underlying monotone relationship with production levels, but can be reduced by increasing use of other, productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels. In some of the policy simulations we evaluate sectoral emission reduction scenarios, using specific cost and emission reduction factors, based on our earlier analysis (Hanemann and Farrell: 2006).

Table 2.1: Emission Categories

Air Pollutants		
1.	Suspended particulates	PART
2.	Sulfur dioxide (SO_2)	SO2
3.	Nitrogen dioxide (NO_2)	NO2
4.	Volatile organic compounds	VOC
5.	Carbon monoxide (CO)	CO
6.	Toxic air index	TOXAIR
7.	Biological air index	BIOAIR
Water Pollutants		
8.	Biochemical oxygen demand	BOD
9.	Total suspended solids	TSS
10.	Toxic water index	TOXWAT
11.	Biological water index	BIOWAT
Land Pollutants		
12.	Toxic land index	TOXSOL
13.	Biological land index	BIOSOL

[9] See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

The model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table 2.1. Our focus in the current study is the emission of CO2 and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues. For more detail, please consult the full model documentation.

An essential characteristic of the BEAR approach to emissions modeling is endogeneity. Contrary to assertions made elsewhere (Stavins et al:2007), the BEAR model permits emission rates by sector and input to be exogenous or endogenous, and in either case the level of emissions from the sector in question is endogenous unless a cap is imposed. This feature is essential to capture structural adjustments arising from market based climate policies, as well as the effects of technological change.

3 NOTES ON THE CAT SCENARIOS

The general results of the CAT scenarios have been discussed in the main body of this document. In this section, a few independent observations are offered from the perspective of current and previous research with the BEAR model.

Aggregate Real Effects on the Economy are Quite Small (Growth is not Threatened)

Despite the political and economic importance of state's climate policy initiatives, the economic burden of the proposed policies is small relative to the California economy. To take two examples, in Scenario 1 the approximate cost of all permits would be less than 2% of the value of output in the target sectors, and a much smaller fraction of state GDP. In a more extreme case, when CAT attains only half its target mitigation and cap and trade makes up the difference in only three sectors (Scenario 8), the permit cost is much higher (about 24% of three-sector output value), but still less than 2% of state GDP. To the extent that the sectoral costs are passed on, they cannot significantly reduce aggregate state income and consumption. In particular, they are much smaller than most climate damage estimates.

Individual Sector Demand, Output, and Employment can Change Significantly (Economic Structure Changes)

Energy fuel and carbon capped sectors can experience important adjustments, but these are offset by expansion elsewhere, including Services, Construction, and Consumer goods. The California economy is seen undergoing an important structural adjustment, reducing aggregate energy intensity and increasing the labor-intensity of state demand and output. These shifts, masked at the aggregate level, may present opportunities for policy makers to mitigate adjustment costs.

In other words, the aggregate results indicate that the policies considered will pose no significant net cost to the California economy. They might raise costs for some firms and individuals, but as a whole the California economy will probably experience higher growth and create more jobs than it would have without this action (even before considering climate damage aversion). The task for

California policymakers in the near term will be to design policies that fairly and efficiently distribute the costs of reducing greenhouse gas emissions.

Real Output and Employment Effects are Smaller than in Previous BEAR Results

The reason for this result is that the CAT scenarios are technology neutral, meaning no innovation or efficiency improvements are anticipated in response to the CAT measures. By contrast, previous BEAR scenarios assumed induced efficiency gains in line with California's historical trend of ~1.4% per year. The assumption of induced efficiency gains was omitted from the main analysis for comparability and to conform with CAT scenario specification. However, the effects of this assumption are examined as additional scenarios in this appendix. As in the past, these efficiency gains are crucial determinants of the growth dividend from California's energy efficiency policies. In particular, the positive results would be much larger and the negative results could easily be reversed. This issue is discussed in greater detail in the next section.

Employment Effects are Positive in the Majority of Scenarios

The reason for this result, as in past BEAR estimates, is re-direction of consumer expenditure from energy/fuels to more labor-intensive goods and services. This is one of the most important economic effects of climate action policy, reducing import dependence on capital-intensive fuels and increasing spending on in-state goods and services. In the last round of CAT estimates, the EDRAM model revealed the same benefits, amplified by migration into California. The current BEAR scenarios do not allow for migration, so its results are smaller for this reason and because of tech-neutrality.

No Significant Leakage is Observed in the BEAR Scenarios

Import and export adjustments are significant in some sectors, but with no discernable interaction with the carbon constraint in the capped sectors. Imports of fuels fall sharply as the policies dictate, but there is negligible evidence of pollution outsourcing in targeted or energy dependent sectors.

No Forgone Damages, Including Local Pollution or Public Health Costs, are Taken Account of in the Results

Over a thirteen year time horizon, and considering the amount of pollution reduction, these could be significant (see e.g. Stern: 2006).

4 IMPLICATIONS OF TECHNOLOGICAL CHANGE

An important characteristic of the CAT scenarios discussed in the main body of this report is technological neutrality. This means that factor productivity, energy use intensities, and other innovation characteristics were held constant across the scenarios. Energy use and pollution levels might change, but the prospect of innovation to reduce energy intensity was not considered. This consideration is important for two reasons. Technological change in favor of energy efficiency has been a hallmark of California's economic growth experience over the last four decades. Over this period California has reduced its aggregate energy intensity by about 1.5% per year, attaining levels that today are 40% below the national average. Moreover, most observers credit this technological progress to California's energy/climate policies, combinations of mandated and incentive based efficiency measures from which the Climate Action Team recommendations are direct descendants.

Thus, energy innovation has been part of the history of the state's economic growth and at the same time a consequence of its policies. For these reasons, it is important to consider the potential contribution of continued innovation to the economic effects of California climate policy. For illustrative purposes, we used the BEAR model for two comparison cases to illustrate what innovation could contribute to the economic impact estimates already discussed.

Tables A_.1-A_.4 report the same aggregate economic variables found in Exhibits 19-22 of the main report. In the first column of each we repeat the BEAR findings, corresponding to technology neutrality. In the Scenario labeled I-Cap, those sectors subject to the emissions cap experience annual emissions efficiency growth of 1.5% during the policy implementation phase (2012-2020). In the scenario labeled I-All, each of the 50 sectors in this implementation of the BEAR model have 1.5% annual efficiency gains over the same period. The latter case corresponds more closely to California's experience, with aggregate average improvements, but is must be emphasized that even these experiments omit he household sector, responsible for over a third of statewide emissions, and thus remain conservative.[10]

If climate action measures continue to improve efficiency, particularly if this improvement is distributed across all sectors of the economy, it could contribution more than 9% more to real GSP by 2020, increase statewide

[10] Some household effects are directly accounted for in the CAT policy scenario that underlies all the counterfactuals.

employment by over 6%, and raise real personal incomes by about 4%. All these results are significantly more dynamic than the technology neutral scenarios, yet California's innovation potential is one of its most robust economic characteristics.

Although these results are best interpreted as indicative, they have two important implications for the state's climate policy research agenda. Firstly, even the modest assumptions about innovation show it has significant potential to make climate action a dynamic growth experience for the state economy. Second, the size and distribution of potential growth benefits is large enough to justify significant commitments to deeper empirical research on these questions.

If the state is to maintain its leadership as a dynamic and innovation oriented economy, it may be essential for climate policy to include explicit incentives for competitive innovation, investing in discovery and adoption of new technologies that offer win-win solutions to the challenge posed by climate change for the state's industries and for consumers. In this way, California can sustain its enormous economic potential and establish global leadership in the world's most promising new technology sector, energy efficiency, as it has done so successfully in ICT and biotechnology.

Table A_.1: Impacts on Real State Output (% Change from Baseline)

Scenarios	BEAR	I-Cap	I-All
Scenario 1	-0.10%	1.17%	8.96%
Scenario 2	-0.20%	1.17%	8.94%
Scenario 3	-0.10%	1.17%	8.96%
Scenario 4	-0.10%	1.17%	8.96%
Scenario 5	-0.20%	0.01%	8.95%
Scenario 6	-0.10%	0.02%	8.96%
Scenario 7	-0.20%	1.15%	8.91%
Scenario 8	-0.30%	-0.06%	8.83%
Scenario 3*	-0.20%	NA	NA

Table A_.3: Impacts on Employment (% Change from Baseline)

Scenarios	BEAR	I-Cap	I-All
Scenario 1	0.20%	0.87%	6.27%
Scenario 2	0.10%	0.87%	6.25%
Scenario 3	0.20%	0.87%	6.27%
Scenario 4	0.20%	0.87%	6.27%
Scenario 5	0.10%	0.17%	6.26%
Scenario 6	0.20%	0.17%	6.27%
Scenario 7	-0.10%	0.82%	6.19%
Scenario 8	-0.50%	0.05%	6.10%
Scenario 3*	-0.20%	NA	NA

Table A_.2: Impacts on Personal Income (% Change from Baseline)

Scenarios	BEAR	I-Cap	I-All
Scenario 1	-0.60%	-0.09%	3.98%
Scenario 2	-0.70%	-0.09%	3.87%
Scenario 3	-0.60%	-0.09%	3.98%
Scenario 4	-0.60%	-0.09%	3.98%
Scenario 5	-0.60%	-0.52%	3.96%
Scenario 6	-0.60%	-0.50%	3.98%
Scenario 7	-0.70%	-0.18%	3.87%
Scenario 8	-0.90%	-0.70%	3.72%
Scenario 3*	-0.80%	NA	NA

Table A_.4: Estimated Emission Allowance Prices

Scenarios	BEAR	I-Cap	I-All
Scenario 1	$22	$15	$5
Scenario 2	$7	$4	$7
Scenario 3	$22	$15	$5
Scenario 4	$22	$15	$5
Scenario 5	$80	$53	$24
Scenario 6	$17	$10	$1
Scenario 7	$206	$151	$87
Scenario 8	$442	$318	$226
Scenario 3*	$9	NA	NA

5 REFERENCES

Roland-Holst, David. 2005. “Berkeley Energy and Resources (BEAR) Model Documentation for a Dynamic California CGE Model for Energy and Environmental Policy Analysis.” Research Paper 0509231, Center for Energy, Resources, and Economic Sustainability, University of California, Berkeley, September.

Roland-Holst, David. 2006a. “Economic Assessment of Some California Greenhouse Gas Control Policies: Applications of the BEAR Model.” In Managing Greenhouse Gas Emissions in California, ed. Michael Hanemann and Alexander Farrell, Chapter 2. University of California at Berkeley: The California Climate Change Center. January.

Roland-Holst, David. 2006b. “Economic Growth and Greenhouse Gas Mitigation in California.” University of California at Berkeley: The California Climate Change Center. August.

Roland-Holst, David. 2007a. “Cap and Trade and Structural transition in the California Economy,” Research Paper 0707121, Center for Energy, Resources, and Economic Sustainability, University of California, Berkeley, April.

Roland-Holst, David. 2007b. “Net Positive: California and the Cost of Curbing Carbon,” Research Paper 0708241, Center for Energy, Resources, and Economic Sustainability, University of California, Berkeley, August

Stavins, Robert N., Judson Jaffe, and Todd Schatski. 2007. “Too Good to be True? An Examination of Three Economic Assessments of California Climate Change Policy,” Working Paper, AEI-Brookings Joint Center for Regulatory Studies, January.

Nicholas Stern (2006). "Stern Review executive summary". New Economics Foundation, London.